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METHOD AND SYSTEM FOR AUTOMATIC AXIAL ROTATION CORRECTION FOR IN VIVO IMAGES

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METHOD AND SYSTEM FOR AUTOMATIC AXIAL ROTATION CORRECTION FOR IN VIVO IMAGES

FIELD OF THE INVENTION

The present invention relates generally to an endoscopic imaging system and, in particular, to axial rotation correction of in vivo images.

BACKGROUND OF THE INVENTION

Several in vivo measurement systems are known in the art. They include swallowed electronic capsules which collect data and which transmit the data to an external receiver system. These capsules, which are moved through the digestive system by the action of peristalsis, are used to measure pH ("Heidelberg" capsules), temperature ("CoreTemp" capsules) and pressure throughout the gastro-intestinal (GI) tract. They have also been used to measure gastric residence time, which is the time it takes for food to pass through the stomach and intestines. These capsules typically include a measuring system and a transmission system, wherein the measured data is transmitted at radio frequencies to a receiver system.

U.S. Patent No. 5,604,531, assigned to the State of Israel, Ministry of Defense, Armament Development Authority, and incorporated herein by reference, teaches an in vivo measurement system, in particular an in vivo camera system, which is carried by a swallowed capsule. In addition to the camera system, there is an optical system for imaging an area of the GI tract onto the imager and a transmitter for transmitting the video output of the camera system. The capsule is equipped with a number of LEDs (light emitting diodes) as the lighting source for the imaging system. The overall system, including a capsule that can pass through the entire digestive tract, operates as an autonomous video endoscope. The electronic capsule images even the difficult to reach areas of the small intestine.

U.S. Patent No. 6,632,175, assigned to Hewlett-Packard Development Company, L. P., and incorporated herein by reference, teaches a design of a swallowable data recorder medical device. The swallowable data

recorder medical device includes a capsule having a sensing module for sensing a biological condition within a body. A recording module is provided including an atomic resolution storage device.

U.S. Patent Application No. 2003/0023150 A1, assigned to Olympus Optical Co., LTD., and incorporated herein by reference, teaches a design of a swallowed capsule-type medical device for conducting examination, therapy, or treatment, which travels through the inside of the somatic cavities and lumens of human beings or animals. Signals, including images captured by the capsule-type medical device, are transmitted to an external receiver and recorded on a recording unit. The images recorded are retrieved in a retrieving unit, displayed on the liquid crystal monitor and compared, by an endoscopic examination crew, with past endoscopic disease images that are stored in a disease imaging database.

One problem associated with the capsule imaging system is that when the capsule moves forward along the GI tract, there inevitably exists an axial rotation of the capsule around its own axis. This axial rotation causes inconsistent orientation of the captured images, which in turn causes diagnosis difficulties.

Hua Lee, *et al.* in their paper entitled "Image analysis, rectification and re-rendering in endoscopy surgery" (see http://www.ucop.edu/research/micro/abstracts/2k_055.html), incorporated herein by reference, describes a video-endoscopy system used for assisting surgeons to perform minimal incision surgery. A scope assistant holds and positions the scope in response to the surgeon's verbal directions. The surgeon's visual feedback is provided by the scope and displayed on a monitor. The viewing configuration in endoscopy is 'scope-centered'. A large, on-axis rotation of the video scope and the camera will change the orientation of the body anatomy. The effect of that is the surgeon easily gets disoriented after repeated rotation of the scope view.

Note, Hua et al. teaches a method for a controllable endoscopic video system (controlled by an human assistant). The axial rotation of the video camera can be predicted and corrected. Furthermore, the axial rotation can be

eliminated by using a robotic control system such as ROBDOC™ (see, http://www.robodoc.com/eng/index.html).

Other endoscopic video systems are uncontrollable systems. The camera is carried by a peristalsis propelled capsule. The axial rotation of the capsule is random, therefore, unpredictable.

There is a need therefore for an improved endoscopic imaging system that overcomes the problems set forth above.

These and other aspects, objects, features and advantages of the present invention will be more clearly understood and appreciated from a review of the following detailed description of the preferred embodiments and appended claims, and by reference to the accompanying drawings.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a digital image processing method for automatic axial rotation correction for in vivo images that includes selecting, as a reference image, a first arbitrary in vivo image from a plurality of in vivo images, and subsequently, finding a rotation angle between a second arbitrary in vivo image selected from the plurality of in vivo images and the reference image. The method next corrects the orientation of the second arbitrary in vivo image, with respect to orientation of the reference image and corresponding to the rotation angle, before finding the rotation angle between other selected in vivo images and the reference image. Additionally, the method corrects for the other selected in vivo images that do not match the reference image's orientation and where there exists a rotation angle between the other selected in vivo images and the reference image.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a prior art block diagram illustration of an in vivo camera system;

FIG. 2 is an exemplary illustration of the concept of an examination bundle according to the present invention;

FIG. 2A is an exemplary illustration of the concept of an examination bundlette according to the present invention;

FIG. 3A is a flowchart illustrating information flow for a real-time abnormality detection method;

FIG. 3B is a flowchart illustrating information flow of the in vivo image with axial rotation correction of the present invention;

FIG. 4 is a schematic diagram of an exemplary examination bundlette processing hardware system useful in practicing the present invention;

FIG. 5 is a flowchart illustrating the in vivo image axial rotation correction method according to the present invention;

Fig. 6A is a graph showing an in vivo imaging system capsule in a GI tract;

Fig. 6B is a graph illustrating three-dimensional coordinate systems of the in vivo imaging system at three locations in a GI tract;

Fig. 6C is a graph illustrating an in vivo image plane and its two-dimensional coordinate system;

Fig. 6D illustrates an in vivo image with an object and another in vivo image with an rotated object;

Fig. 7 is a graph illustrating an optic flow image;

Fig. 8A illustrates an optic flow image simulating a camera moving forward along its optical axis while rotating around its optical axis;

Fig. 8B illustrates an optic flow image simulating a camera moving rotating around its optical axis, and

Fig. 8C illustrates an optic flow image simulating a camera rotating around its optical axis.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various aspects of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that

the present invention may be practiced without the specific details presented herein. Furthermore, well-known features may be omitted or simplified in order not to obscure the present invention.

During a typical examination of a body lumen, the in vivo camera system captures a large number of images. The images can be analyzed individually, or sequentially, as frames of a video sequence. An individual image or frame without context has limited value. Some contextual information is frequently available prior to or during the image collection process; other contextual information can be gathered or generated as the images are processed after data collection. Any contextual information will be referred to as metadata. Metadata is analogous to the image header data that accompanies many digital image files.

FIG. 1 shows a block diagram of the in vivo video camera system described in U.S. Patent No. 5,604,531. The system captures and transmits images of the gastro-intestinal (GI) tract while passing through the gastro-intestinal lumen. The system contains a storage unit **100**, a data processor **102**, a camera **104**, an image transmitter **106**, an image receiver **108**, which usually includes an antenna array (not shown herein), and an image monitor **110**. Storage unit **100**, data processor **102**, image monitor **110**, and image receiver **108** are located outside the patient's body. Camera **104**, as it transits the GI tract, is in communication with image transmitter **106** located in capsule **112** and image receiver **108** located outside the body. Data processor **102** transfers frame data to and from storage unit **100** while the former analyzes the data. Data processor **102** also transmits the analyzed data to image monitor **110** where a physician views it. The data can be viewed in real time or at some later date.

Referring to Figure 2, the complete set of all images captured during the examination, along with any corresponding metadata, will be referred to as an examination bundle **200**. The examination bundle **200** consists of a collection of image packets **202** and a section containing general metadata **204**.

An image packet **206** comprises two sections: the pixel data **208** of an image that has been captured by the in vivo camera system, and image specific

metadata **210**. The image specific metadata **210** can be further refined into image specific collection data **212**, image specific physical data **214** and inferred image specific data **216**. Image specific collection data **212** contains information such as the frame index number, frame capture rate, frame capture time, and frame exposure level. Image specific physical data **214** contains information such as the relative position of the capsule when the image was captured, the distance traveled from the position of initial image capture, the instantaneous velocity of the capsule, capsule orientation, and non-image sensed characteristics such as pH, pressure, temperature, and impedance. Inferred image specific data **216** includes location and description of detected abnormalities within the image, and any pathologies that have been identified. This data can be obtained either from a physician or by automated methods.

The general metadata **204** contains such information as the date of the examination, the patient identification, the name or identification of the referring physician, the purpose of the examination, suspected abnormalities and/or detection, and any information pertinent to the examination bundle **200**. It can also include general image information such as image storage format (e.g., GIF, TIFF or JPEG-based), number of lines, and number of pixels per line.

Referring to Fig. 2A, the image packet **206** and the general metadata **204** are combined to form an examination bundlette **220** suitable for real-time abnormality detection.

It will be understood and appreciated that the order and specific contents of the general metadata or image specific metadata may vary without changing the functionality of the examination bundle.

Referring now to Fig. 3A and specific components shown in Fig. 2, an exemplary application of the capsule in vivo imaging system is described. Fig. 3A is a flowchart illustrating a real-time automatic abnormality detection method. In Fig. 3A, an in vivo imaging system **300** can be realized by using systems such as the swallowed capsule described in U.S. Patent No. 5,604,531. An in vivo image **208** (as shown in Fig. 2) is captured in an in vivo image acquisition step **302**. In a step of In Vivo Examination Bundlette Formation **304**, the image **208** is

combined with image specific data **210** to form an image packet **206**. The image packet **206** is further combined with general metadata **204** and compressed to become an examination bundlette **220**. The examination bundlette **220** is transmitted to a proximal in vitro computing device through radio frequency in a step of RF transmission **306**. An in vitro computing device **320** is either a portable computer system attached to a belt worn by the patient or in near proximity. Alternatively, it is a system such as shown in Fig.4 and will be described in detail later. The transmitted examination bundlette **220** is received in the proximal in vitro computing device 320 by an In Vivo RF Receiver **308**.

Data received in the in vitro computing device 320 is examined for any sign of disease in Abnormality detection operation **310**. Details of the step of abnormality detection can be found in commonly assigned, co-pending U.S. Patent Application Serial No. (our docket 86558), entitled "METHOD AND SYSTEM FOR REAL-TIME AUTOMATIC ABNORMALITY DETECTION OF IN VIVO IMAGES", and which is incorporated herein by reference.

Fig. 3B shows a diagram of information flow of the present invention. To ensure effective detection and diagnosis of an abnormality, images from RF Receiver **308** are adjusted in a step of Image axial rotation correction **309** before the abnormality detection operation **310** takes place (see Fig. 3B).

The step of Image axial rotation correction **309** is specifically detailed in Fig. 5. Any alarm signals from step **310** will be sent to a local site **314** and to a remote health care site **316** through communication connection **312**. An exemplary communication connection **312** could be a broadband network connected to the in vitro computing system **320**. The connection from the broadband network to the in vitro computing system **320** could be either a wired connection or a wireless connection. Again, the in vitro computing device **320** could be a portable computer system attached to a belt worn by the patient.

A plurality of images **501** received from RF receiver **308** are input to operation **502** of "Getting two images" (a first arbitrary image and a second arbitrary image) I_n and $I_{n+\delta}$, where n is an index of an image sequence, δ is an index offset. An exemplary value for δ is 1. The in vivo camera is carried by a

peristalsis propelled capsule. Axial rotation of the capsule causes the image plane to rotate about its optical axis. Exemplary images in step **502** are shown in Fig. 6B. For clarity, detailed description of the remaining operational steps (503, 504, 505, 506, 507, 508, 509, 510, 514, 516, 518, and 520) of Fig. 5 are discussed in a later section, once the angular relationship between successive image planes is explained.

Along a GI tract **606**, there are images (planes) $I_{n-\delta}$ **(608)**, I_n **(610)** and $I_{n+\delta}$ **(612)** at GI positions $p_{n-\delta}$ **(607)**, p_n **(609)** and $p_{n+\delta}$ **(611)** respectively. There are three-dimensional coordinate systems, $S_{n-\delta}$ **(614)**, S_n **(616)** and $S_{n+\delta}$ **(618)** attached to images $I_{n-\delta}$, I_n and $I_{n+\delta}$ accordingly.

The X and Y axes of the three-dimensional systems $S_{n-\delta}$ **(614)**, S_n **(616)** and $S_{n+\delta}$ **(618)** are aligned with the V and U axes of a two-dimensional coordinate system of the corresponding images (planes) $I_{n-\delta}$ **(608)**, I_n **(610)** and $I_{n+\delta}$ **(612)**. An exemplary two-dimensional coordinate system **(620)** of an image with the U and V axes is shown in Fig. 6C. Note that the origin of the two-dimensional coordinate system is at the center of the image plane. The Z axes of the three-dimensional systems $S_{n-\delta}$ **(614)**, S_n **(616)** and $S_{n+\delta}$ **(618)** are perpendicular to their corresponding image planes $I_{n-\delta}$ **(608)**, I_n **(610)** and $I_{n+\delta}$ **(612)**. The Z axes of the three-dimensional systems $S_{n-\delta}$ **(614)**, S_n **(616)** and $S_{n+\delta}$ **(618)** are aligned with optical axes of the in vivo camera at the corresponding positions where images $I_{n-\delta}$ **(608)**, I_n **(610)** and $I_{n+\delta}$ **(612)** are captured. When the camera rotates around its optical axis, the three-dimensional system attached to the camera image plane also rotates around its Z axis. The rotation angle is defined respective to a right-hand system or a left-hand system as is known to ordinary people skilled in the art. This rotation makes fixed objects (the inner walls of the GI tract) in the three-dimensional space rotate in an opposite direction in the rotated three-dimensional coordinate system. This phenomenon is illustrated in Fig. 6D. An object **630** is projected onto image plane I_n **(610)** at position p_n **(609)**. Object **630** has four corner points **632, 634, 636** and **638**. When the in

vivo camera advances to position $p_{n+\delta}$ **(611)** there is a counterclockwise rotation $\theta_{n+\delta}$ **(615)** around the Z axis associated with the camera forward motion. The object in image $I_{n+\delta}$ **(612)** captured at position $p_{n+\delta}$ **(611)** appears to rotate clockwise with $-\theta_{n+\delta}$ degrees in addition to a magnification effect due to the camera forward motion. Object **631** has four corner points **633, 635, 637** and **639**. If image plane I_n **(610)** is taken as a reference plane, the four points **(633, 635, 637** and **639)** in image plane $I_{n+\delta}$ **(612)** appear to move away from their original positions (points **632, 634, 636** and **638)** in the reference image plane. This motion of points in the image plane can be described using a common terminology, 'optic flow' which is widely adopted in the computer vision community.

Fig. 7 illustrate the optic flow image **710** of object **630** in image **610** (shown in Fig. 6D). Arrows **732, 734, 736** and **738** indicate the motion direction of points **632, 634, 636** and **638** to points **633, 635, 637** and **639** of object **631** in a reference plane.

The method of the present invention is to determine the rotation angle θ , in general, between consecutive image coordinate systems (angle between the V axes or between U axes of two images) in order to perform rotation correction. This task is accomplished first by finding corresponding point pairs in consecutive images in a step of Corresponding point pair searching **504**. Exemplary corresponding point pairs are **632-633, 634-635, 636-637**, and **638-639** (as shown in Fig. 6D). There are abundantly well known algorithms to fulfill this corresponding point pair searching task. For example, a phased-based image motion estimation method that is not sensitive to low-pass variations in image intensity where shadows and illumination vary (see "Phase-based Image Motion Estimation and Registration," by Magnus Hemmendorff, Mats T. Andersson, and Hans Knutsson, http://www.telecom.tuc.gr/paperdb/icassp99/PDF/AUTHOR/IC991287.PDF).

The estimation of angle between two consecutive images is performed in step **506** (shown in Fig. 5) of Rotation angle estimation. In general,

this estimation can be realized by using algorithms such as 2D-2D absolute orientation detection (see "Computer and Robot Vision," by Robert M. Haralick and Linda G. Shapiro) as an exemplary scheme.

Once again, referring to Fig. 6D, Using image planes I_n **(610)** and $I_{n+\delta}$ **(612)** as exemplary images, denote T 2D coordinate points from I_n **(610)** by $p_1^n, \cdots, p_T^n$ (for example, points **632**, **634**, **636** and **638**, and here $T=4$). These could correspond to the points in $I_{n+\delta}$ **(612)** denoted by $p_1^{n+\delta}, \cdots, p_T^{n+\delta}$ (for example, points **633**, **635**, **637** and **639**). Note, this correspondence has been accomplished in step **504** (shown in Fig. 5) of Corresponding point pair searching. This 2D orientation detection attempts to determine from the corresponding point pairs (for example, pairs **632-633**, **634-635**, **636-637**, and **638-639**) a more precise estimate of a rotation matrix R and a translation d such that $p_t^{n+\delta} = Rp_t^n + d, t = 1, \ldots, T$. Since errors are likely embedded in step of Corresponding point pair searching **504**, the real problem becomes a minimization problem. Determine R and d such that the weighted sum of the residual errors ε^2 is minimized:

$$\varepsilon^2 = \sum_{t=1}^{T} w_t \left\| p_t^{n+\delta} - \left(Rp_t^n + d \right) \right\|^2 \qquad \textbf{(1)}$$

The weights $w_t \geq 0$ and $\sum_{t=1}^{T} w_t = 1$. Exemplary value of the weights could be $w_t = 1/T$.

First, taking the partial derivative of Equation (1) with respective to the translation d and setting the partial derivative to 0 yields

$$d = \bar{p}^{n+\delta} - R\bar{p}^n \qquad \textbf{(2)}$$

where $\bar{p}^{n+\delta} = \sum_{t=1}^{T} w_t p_t^{n+\delta}$ and $\bar{p}^n = \sum_{t=1}^{T} w_t p_t^n$. Applying Equation (2) in Equation (1) results in

$$\varepsilon^2 = \sum_{t=1}^{T} w_t \left[\left(p_t^{n+\delta} - \bar{p}^{n+\delta}\right)' \left(p_t^{n+\delta} - \bar{p}^{n+\delta}\right) - 2\left(p_t^{n+\delta} - \bar{p}^{n+\delta}\right) R \left(p_t^n - \bar{p}^n\right) + \left(p_t^n - \bar{p}^n\right)' \left(p_t^n - \bar{p}^n\right) \right] \textbf{(3)}$$

Notice the fact that

$$R = \begin{bmatrix} \cos(\theta_{n+\delta}) & -\sin(\theta_{n+\delta}) \\ \sin(\theta_{n+\delta}) & \cos(\theta_{n+\delta}) \end{bmatrix} \qquad \textbf{(4)}$$

Notice also that every point such as **632**, **634**, **636**, **638**, **633**, **635**, **637** or **639** in the image plane is represented by a two-dimensional vector in the U-V coordinate system as shown in Fig. 6C. Therefore, p_t^n and $p_t^{n+\delta}$ can be expressed as

$$p_t^n = \begin{pmatrix} p_{u,t}^n \\ p_{v,t}^n \end{pmatrix} \text{ and } p_t^{n+\delta} = \begin{pmatrix} p_{u,t}^{n+\delta} \\ p_{v,t}^{n+\delta} \end{pmatrix} \quad \textbf{(5)}$$

and

$$\bar{p}^n = \begin{pmatrix} \bar{p}_u^n \\ \bar{p}_v^n \end{pmatrix} \text{ and } \bar{p}^{n+\delta} = \begin{pmatrix} \bar{p}_u^{n+\delta} \\ \bar{p}_v^{n+\delta} \end{pmatrix} \quad \textbf{(6)}$$

Applying Equations (4), (5) and (6) to Equation (3) and setting to zero the partial derivative of ε^2 with respect to $\theta_{n+\delta}$ results in $0 = A\sin(\theta_{n+\delta}) + B\cos(\theta_{n+\delta})$ where $A = \sum_{t=1}^{T} w_t \left[(p_{u,t}^{n+\delta} - \bar{p}_u^{n+\delta})(p_{u,t}^n - \bar{p}_u^n) + (p_{v,t}^{n+\delta} - \bar{p}_v^{n+\delta})(p_{v,t}^n - \bar{p}_v^n) \right]$ and

$B = \sum_{t=1}^{T} w_t \left[(p_{u,t}^{n+\delta} - \bar{p}_u^{n+\delta})(p_{u,t}^n - \bar{p}_u^n) - (p_{v,t}^{n+\delta} - \bar{p}_v^{n+\delta})(p_{v,t}^n - \bar{p}_v^n) \right]$.

The absolute value of the rotation angle $\theta_{n+\delta}$ can be computed as

$$|\theta_{n+\delta}| = \cos^{-1}\left(A / \sqrt{A^2 + B^2}\right) \quad \textbf{(7)}$$

After finding the absolute value of the rotation angle (for example, $\theta_{n+\delta}$) between two consecutive image planes (for example, planes I_n **(610)** and $I_{n+\delta}$ **(612)**), the next step is to find the rotation direction, or the sign of the rotation angle in a step of Rotation angle sign detection **508**. The operation of rotation angle sign detection 508 is explained by using a computer-driven simulated case.

Fig. 8 displays the computer simulated optic flow of a set of 2D points (fourteen points) in two consecutive image planes, for example, planes I_n **(610)** and $I_{n+\delta}$ **(612)** (shown in Fig. 6B). These fourteen points are the perspective projections of fourteen non-coplanar points in the three-dimensional space. The focal length of the simulated camera is one unit (exemplary unit is inch). Image plane I_n **(610)** is used as a reference plane. With respect to image plane I_n **(610)**, image plane $I_{n+\delta}$ **(612)** (in fact, the camera) rotates an exemplary 18 degrees clockwise around its optical axis that is aligned with the Z-axis of the three-dimensional coordinate system. Image plane $I_{n+\delta}$ **(612)** (in fact, the camera)

also moves forward along its optical axis, or the Z-axis of the three-dimensional coordinate system, by an exemplary distance of 0.5 units (exemplary unit is inch) toward the cloud of fourteen non-coplanar points in the three-dimensional space. Arrows such as **806** in graph **802** of Fig. 8A illustrate the optic flow of imaged points such as **804** moving from their positions in image plane I_n **(610)** to their positions in image plane $I_{n+\delta}$ **(612)**.

Recall that the simulated motion includes translation along the Z-axis (moving forward) and rotation around the Z-axis. Hence, arrows such as **806** can be decomposed into two components: a translational component and a rotational component. Graph **812** in Fig. 8B illustrates the rotational component of optic flow in Fig. 8A. Arrow **816** is the rotational component of arrow **806** for point **804** (shown in Fig. 8A) due to the rotation of the camera. Graph **822** in Fig. 8C illustrates the translational component of optic flow in Fig. 8A. Arrow **826** is the translational component of arrow **806** for point **804** (shown in Fig. 8A) due to the forward motion of the camera. Notice that image point **804** is a projection of a three-dimensional point on the X axis in the three-dimensional space. If the camera has only translation motion along its optical axis or the Z-axis of the three-dimensional coordinate system, the new position of point **804** resides on the V axis of the image plane (see exemplary arrow **826** in graph **822**). This rule applies to other points on the V axis. Likewise, if the camera has only translation motion along its optical axis or the Z-axis of the three-dimensional coordinate system, the new position of a point on U axis resides on the U axis of the new image plane. In general, if the camera has only translation motion along its optical axis or the Z-axis of the three-dimensional coordinate system, the new position of a point anywhere in the image plane is on a line passing through the point and the origin. Now returning back to Fig. 8A, optic flow arrow **806** for point **804** pointing to negative U direction reveals that there exists a rotational component of the optic flow pointing to the negative U direction as well, just as arrow **816** shown in Fig. 8B. A rotational component of the optic flow pointing to the negative U direction indicates that the camera rotates clockwise. On the other hand, a rotational component of the optic flow pointing to the positive U direction indicates that the

camera rotates counterclockwise. Therefore, by evaluating the optic flow of points on the V axis, the direction (of the sign) of the rotation angle of the camera can be determined. People skilled in the art can easily extend this analysis to points that are not on the V axis. As for the simulated case, using Equations (1) through (7) and the sign detection method stated above, the rotation angle is computed as 17.9 degrees clockwise from the coordinate system of image plane I_n **(610)** to the coordinate system of image plane $I_{n+\delta}$ **(612)** (both are shown in Fig. 6D).

Referring again to Fig. 5, there is a step of Rotation angle accumulation **514**. For a sequence of in vivo images, the user could select any one image among the available images as the reference image and apply axial rotation correction to all the other images. The corrected images are not necessarily consecutive images of the reference image. For example, if image $I_{n-\delta}$ is selected as the reference image, then image $I_{n+\delta}$ has to be rotated by an angle $\theta_{n+\delta}$ so that image $I_{n+\delta}$ will have the same orientation as image $I_{n-\delta}$. Image points matching algorithms such as optic flow computation performs best when they are applied to two images with extensive overlaps (regions having the same objects). Obviously, image $I_{n+\delta}$ has more overlaps with image I_n than with image $I_{n-\delta}$. So the real rotation angle $\theta_{n+\delta}$ for orientation correction, if $I_{n-\delta}$ is selected as the reference image, is the accumulated rotation angle from $I_{n-\delta}$ to $I_{n+\delta}$ computed using Equations (1) through (7) and the sign detection method stated above. In step **516** of Orientation correction, compute

$\hat{I}_{n+\delta} = \hat{R} I_{n+\delta}$, where $\hat{R} = \begin{bmatrix} \cos(-\theta_{n+\delta}) & -\sin(-\theta_{n+\delta}) \\ \sin(-\theta_{n+\delta}) & \cos(-\theta_{n+\delta}) \end{bmatrix}$. The new $\hat{I}_{n+\delta}$ has the same orientation as $I_{n-\delta}$, if $I_{n-\delta}$ is selected as the reference image.

The flow chart in Fig. 5 is an example embodiment of the present invention, where the axial rotation correction starts from I_0. That is, n is initialized as zero. Set δ to one. Use I_0 as the reference image, find the rotation angle and the direction of the angle for I_1 using operations **504, 506, 508** and **514.**

After I_1 is axial rotation corrected, an operation query **518** is performed to see if all images are processed. If so, the algorithm goes to ending operation **520**, otherwise, the algorithm increases n by δ, then gets I_2. Use the original I_1 (before axial rotation correction) to find the angle between I_1 and I_2. The process continues until all the images are corrected.

The axial rotation correction has been formulated in terms of optic flow technology. People skilled in the art should be able to formulate the problem using other technologies such as motion analysis, image correspondence analysis and so on. The axial rotation correction can be realized in real-time or offline.

Fig. 4 shows an exemplary of an examination bundlette processing, including the axial rotation correction hardware system useful in practicing the present invention that includes a template source **400** and an RF receiver **412**. The template from the template source **400** is provided to an examination bundlette processor **402**, such as a personal computer, or a work station such as a Sun Sparc™ workstation. The RF receiver 412 passes the examination bundlette to the examination bundlette processor **402**. The examination bundlette processor **402** preferably is connected to a CRT display **404**, an operator interface, such as a keyboard **406** and/or a mouse **408**. Examination bundlette processor **402** is also connected to computer readable storage medium **407**. The examination bundlette processor **402** transmits processed and adjusted digital images including axial rotation correction and metadata to an output device **409**. Output device **409** can comprise a hard copy printer, a long-term image storage device, or another processor networked together. The examination bundlette processor **402** is also linked to a communication link **414** or a telecommunication device connected, for example, to a broadband network.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

100	Storage Unit
102	Data Processor
104	Camera
106	Image Transmitter
108	Image Receiver
110	Image Monitor
112	Capsule
200	Examination Bundle
202	Image Packets
204	General Metadata
206	Image Packet
208	Pixel Data
210	Image Specific Metadata
212	Image Specific Collection Data
214	Image Specific Physical Data
216	Inferred Image Specific Data
220	Examination Bundlette
300	In Vivo Imaging system
302	In Vivo Image Acquisition
304	Forming Examination Bundlette
306	RF Transmission
306	Examination Bundlette Storing
308	RF Receiver
309	Image axial rotation correction
310	Abnormality Detection
312	Communication Connection
314	Local Site
316	Remote Site
320	In Vitro Computing Device
400	Template source

402	Examination Bundlette processor
404	Image display
406	Data and command entry device
407	Computer readable storage medium
408	Data and command control device
409	Output device
412	RF transmission
414	Communication link
501	images
502	Getting two images
503	image
504	Corresponding point pair searching
505	image
506	Rotation angle estimation
507	angle
508	Rotation angle sign detection
509	angle
510	a step
514	Rotation angle accumulation
516	Orientation correction
518	All images done?
520	end
602	GI tract
604	capsule
606	GI tract Trajectory
607	position point
608	image plane
609	position point
610	image plane
611	position point
612	image plane

614	coordinate system
615	an angle
616	coordinate system
618	coordinate system
620	two-dimensional coordinate system
630	an image object
631	an image object
632	an image point
633	an image point
634	an image point
635	an image point
636	an image point
637	an image point
638	an image point
639	an image point
710	an optic flow image
732	an arrow
734	an arrow
736	an arrow
738	an arrow
802	a simulated camera motion optic flow image
804	an image point
806	an arrow
812	a simulated camera motion optic flow image
816	an arrow
822	a simulated camera motion optic flow image
826	an arrow